

University of Illinois at Urbana-Champaign's GATE Center for Advanced Automotive Bio-Fuel Combustion Engines

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University of Illinois at Urbana-Champaign

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Overview

Timeline

- Start: October 2005
- Finish: September 2012
- 40% Complete

Budget

- Total Project Funding
 - DOE: \$592,350
 - UIUC:\$157,179
- Funding received
 - FY08:\$41,000
 - FY09:\$29,177

Barriers

Educational and research challenges

- Bio- vs. -fuels: currently an educational disconnect
- Biofuel automotive combustion with high efficiency and low emissions is not a direct extrapolation of current automotive practices
- Biofuel properties relevant to automotive combustion remain an almost uncharted area

Partners

Local and International

- | | |
|--|-----------------------|
| •Energy Biosciences Institute | •Cummins |
| •University of Salento, Italy | •Quantlogic |
| •National Technical University of Athens, Greece | •Caterpillar |
| •Volkswagen, Europe | •Deere & Company |
| •Gamma Technologies | •BP |
| •University of Florida | •Incobrasa Industries |



Objectives

- Set up a comprehensive syllabus that will enrich the technical expertise of graduate students of thermal/automotive sciences in agricultural/biological issues related to biofuels and vice-versa.
- Provide a channel through which well established theoretical, computational, and experimental methodologies can be focused so that the potential of biofuels for automotive combustion is fully explored.
- Develop state-of-the-art techniques for automotive R&D with a particular emphasis on laser diagnostics, modeling, and multi-dimensional computations.
- Establish a mutually beneficial strong link with both the automotive and agricultural industry.



Milestones

Phase II: September 2007 –September 2010

Fully investigate potential of biofuels for automotive combustion, provide group of highly skilled scholars and engineers to develop new technology, and transfer knowledge on novel and environmentally friendly fuels and on advanced engine designs to industry

Month/Year	Milestone
April 2009	Web resource for GATE Center to go public
May 2009	Certification process for graduate students to be approved
Ongoing	Fundamental and applied research projects on biofuel properties and combustion
Ongoing	Knowledge transfer to industry via collaborations, meetings and conferences
Ongoing	Identification of novel fuels for investigation (butanol, baelene)



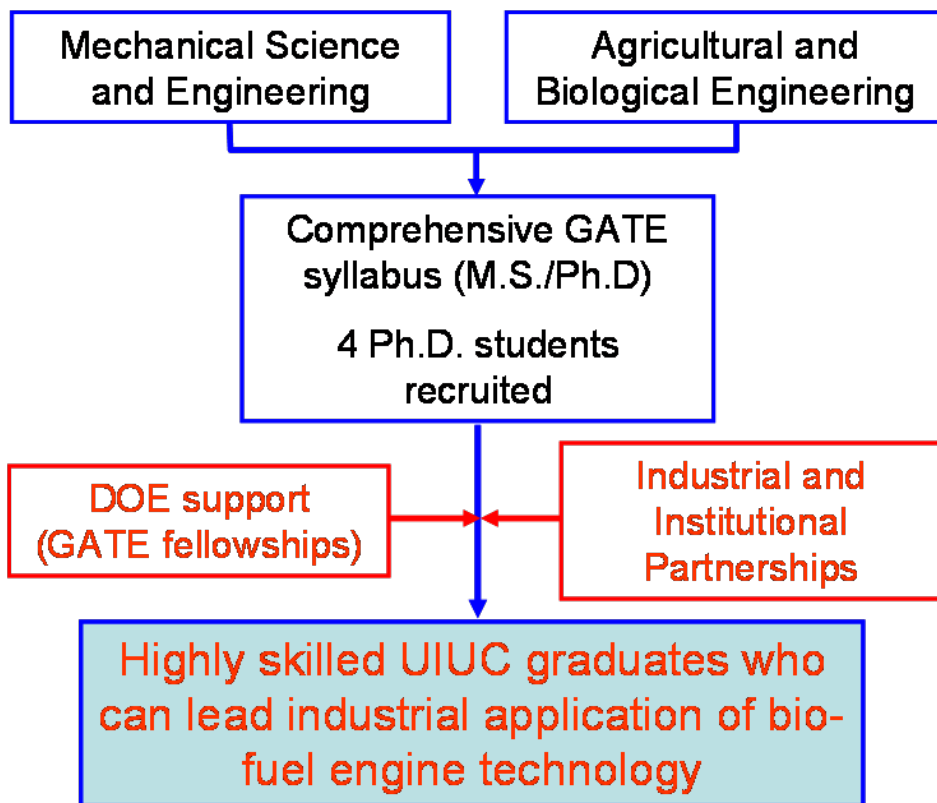
Overall Approach

Establish a high-quality interdisciplinary program at the M.S. and the Ph.D. level that will bridge the current educational disconnect between mechanical and biological aspects of biofuel technology and will integrate educational initiatives and collaborative research projects

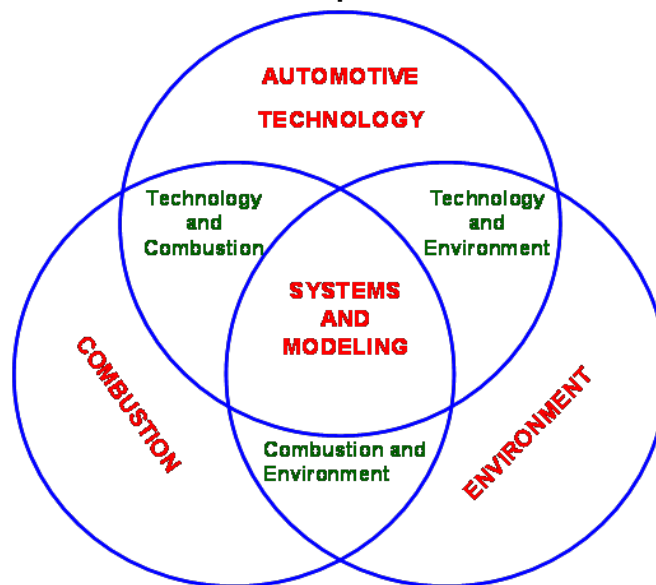
- An interdisciplinary curriculum that provides comprehensive, advanced training on automotive biofuel combustion to students that approach the subject both from both Mechanical Engineering and Agricultural/Biological Engineering backgrounds has been set up.
- Seminal research projects of current interest have been identified by the PIs and have been assigned to GATE fellows The input of the Industrial Advisory Board will be crucial for the determination of future research directions.
- Industrial internships that will constitute a required program component.

Overall Approach

GATE Center Structure



Core Competencies



Domains

- Biofuels and Properties
- Fuel Injection Control and Optimization
- Electro spray Systems for Fuels
- Fuel Injection, Ignition, Combustion and Emissions Modeling
- Engine Performance and Emissions Evaluation
- In-Cylinder Diagnostics
- Emissions Reducing Technologies



Accomplishments

Progress towards Objectives

- Performance measures
 - Comparison with proposed milestones
 - Student participation and evaluation
 - Research productivity (publications, presentations)
- The project is on time with respect to Phase II tasks
 - Establishment of interdisciplinary curriculum
 - Research projects and thesis work (ongoing)
 - Students participate in industrial internships (Caterpillar)
- 34 students involved in the seminar series, 20 enrolled in new class, numbers above campus averages. Student recommendations instrumental in co-PI receiving Society of Automotive Engineers Ralph R. Teetor Educational Award 2009.
- 21 archival publications, one book chapter and 18 conference papers by the 3 co-PIs and the 11 supported students in the second year.



Accomplishments - Educational

- 7 Ph.D. students supported by GATE scholarships
- Students nearing completion of GATE certificate
- Graduate seminar class with presentations from GATE scholars and invited speakers
- New and modified courses (*TAM 537: Experimental Methods of Fluid Mechanics*, *ME 501: Combustion Fundamentals*) offered by Center and ABE faculty.
- Energy and Sustainability Engineering (EaSE) graduate option program formalized at the University of Illinois. GATE fellows will be eligible for EaSE certificate.
- Center faculty membership of departmental and campus Energy Committees

Accomplishments – Educational

Automotive Bio-fuel Combustion Syllabus

The GATE program on “Advanced Automotive Bio-Fuel Combustion Engines” is a three-semester long, 15-credit-hours program. 3 credit hours (1 per semester) are given by the seminar class on Automotive Bioenergy. 12 credit hours are completed by taking one 4 hour course from each of the following groups.

Fundamentals

- ME 404 – Intermediate Thermodynamics
- **ME 501 – Combustion Fundamentals***
- ABE 436 – Renewable Energy Systems

*Modified Course

Core Specialty

- ME 403 – Internal Combustion Engines
- ABE 466 – Engineering Off-road Vehicles

Electives

- ME 503 Design of Internal Combustion Engines
- ME 598 Laser Diagnostics for Thermal/Fluids Engineering
- **TAM 537 Experimental Methods of Fluid Mechanics****
- ABE 488 Bioprocessing Grains for Fuels

**New Course



Accomplishments – Educational

Student and faculty participation

- All 26 students involved in the program so far participated in the seminar class ME 598: “*Automotive Bio-energy*”. The students were required to investigate a wide range of bio-fuel related issues (mechanical, agricultural, chemical, economical, legal) and give half-hour presentations.
- Weekly sessions with typically two student presenters. Students supported on GATE fellowships gave 1 hour-long presentations of their research.
- External speakers
 - Christopher Cadou (Univ. Maryland), Yankun Jiang (Tsinghua Univ.), Xinlei Zhang (UIUC), Dennis Assanis (Univ. Michigan), Daniel Rosner (Yale University), Shijin Shuai (Huazhong Univ. of Sci. & Tech.), Alessandro Gomez (Yale University), Robert Sawyer (UC Berkeley and California Clean Air Board), Hongwei Cui (Shenzhen Polytechnic), Ann Marie Sastry (Univ. Michigan), Wei Wang (Wuhan University of Technology, China), Nibert Peters (Technical Univ. Aachen), Elaine Oran (Naval Research Lab), John Abraham (Purdue University)
- Three Ph.D. GATE students (to Univ. of Delaware, Air Liquide, Packer Engineering) and one M.S. GATE student (Sargent and Lundy) graduated

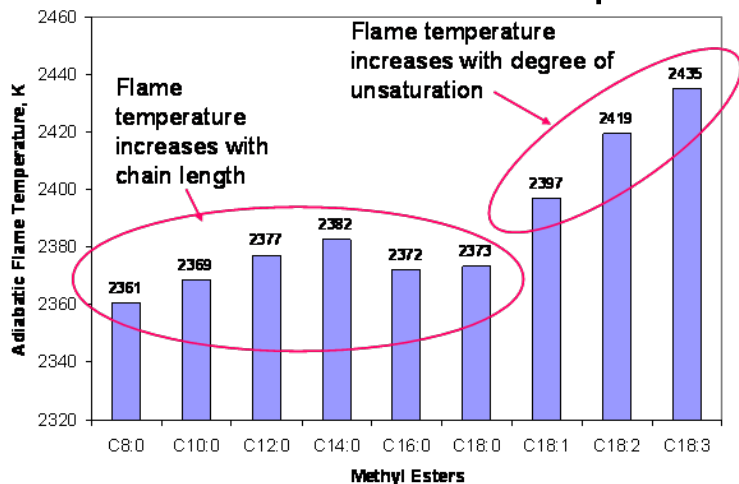


Accomplishments – Educational – New/Modified Courses

- **TAM 537: Experimental Methods of Fluid Mechanics:** Intended as a rigorous introduction to measurement and analysis methods often used in experimental fluid mechanics, including: signal processing, random data and signal analysis, analog and digital data processing, pressure measurement, thermal anemometry, imaging methods, and particle-image velocimetry.
 - Complemented ME 598 (Laser Diagnostics for Thermal and Fluids Engineering) that focused on species measurements.
 - Focus on “hands-on” experimental experience. Will be offered once annually.
- **ME 501 – Combustion Fundamentals:** The syllabus of the course was modified by a new instructor in order to include topics such as:
 - Combustion Waves (Rankine-Hugoniot relations, deflagrations, detonations)
 - Ignition, extinction and flammability limits
 - Multi-dimensional premixed flames
 - Intrinsic combustion instabilities
 - Turbulent combustion
 - Spray combustion

Accomplishments – Research

Biodiesel Property Measurement and Computation for Combustion Modeling

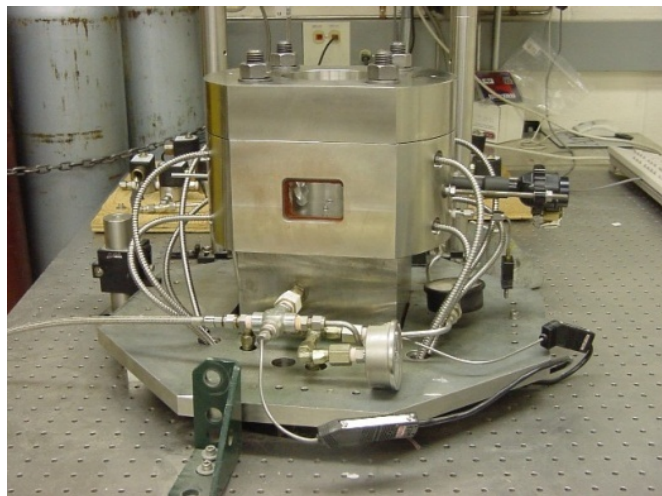


- Computed adiabatic flame temperature for individual methyl esters increased with increasing chain length and degree of unsaturation
- Evidence that increased levels of unsaturated methyl esters within biodiesel can increase flame temperature and thus create higher levels of NO_x emissions

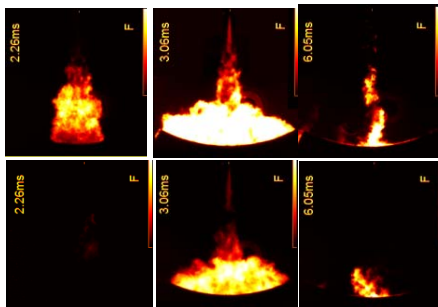
- Constructed fuel library consisting of various biofuels for a combustion model built with GT-Power software to study engine performance and emissions
- Fuel property predictions in library for diesel fuel, soybean biodiesel, and rapeseed biodiesel based on methyl ester composition
- Exploration of next generation biodiesel from algae

Biodiesel Fuel Library for GT-Power	
Liquid Properties	Vapor properties
Heat of Vaporization	C, H, O, N in molecule
Density	Lower Heating Value
Enthalpy	Enthalpy
Viscosity	Viscosity
Thermal Conductivity	Thermal Conductivity
	Critical Temp. and Press.

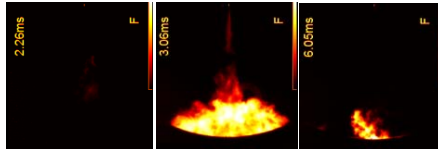
Biodiesel Combustion in a Constant-Volume Combustion Chamber



B0:

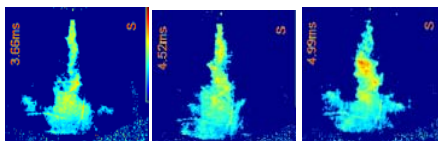


B100:

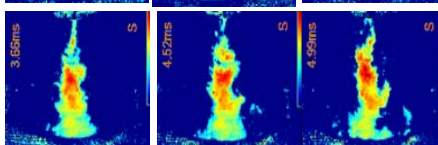


Flame
Luminosity

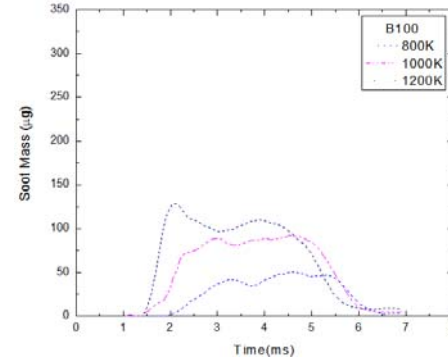
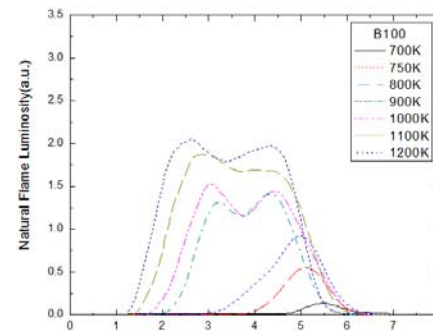
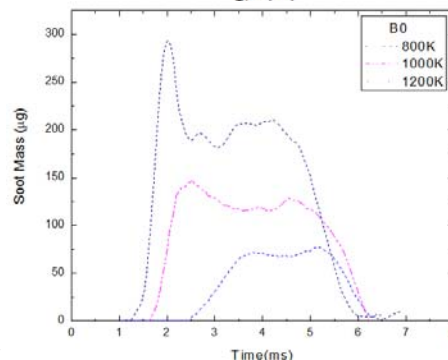
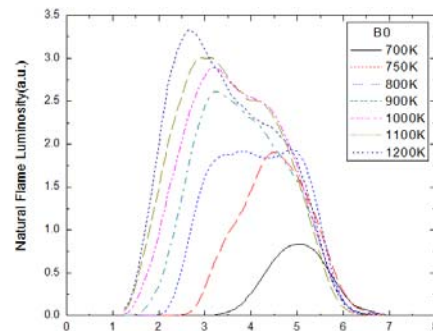
B0:



B100:



Soot
Formation



• Different fuels were investigated under different ambient density and ambient temperature. 15 Kg/m³ ambient density and 21% ambient O₂ concentration were used to simulate the real engine cylinder environment.

• B100 had a relatively lower flame luminosity and soot emission than B0 under the same condition. especially at higher temperature.

Common-Rail V6 Engine Fueled with Diesel and Biodiesel Blends

Goal

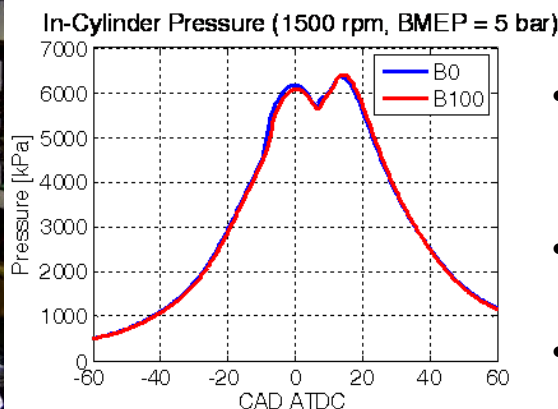
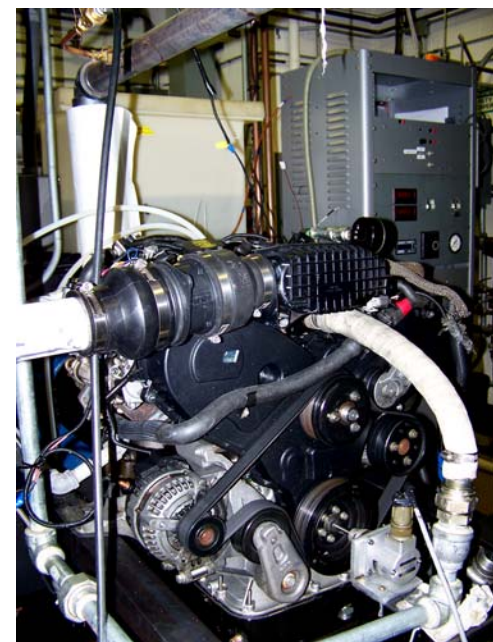
- To study performance and emissions of a common-rail V6 diesel engine fueled with biodiesel and its blends.

Approach

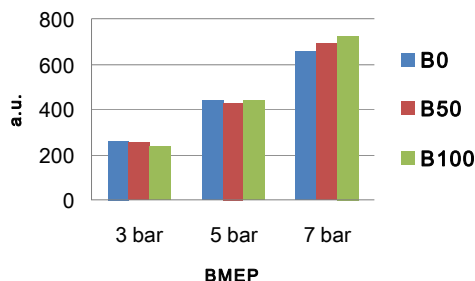
- A configurable ECU, coupled with ETAS INCA software is capable of changing all engine parameters.
- A Labview program was developed to monitor and control the engine.
- An independent PID control system is used to vary intake pressure and temperature.

Preliminary Results

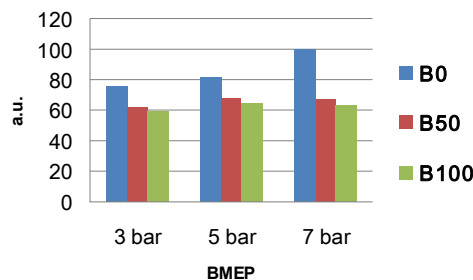
- Default ECU calibrations will change engine parameters like injection timings and EGR when using biodiesel.
- Production ECU is not optimized for biodiesel combustion.
- NOx emissions increased by about 10% at higher loads; soot decreased by 20%.



NOx emission
1500 rpm

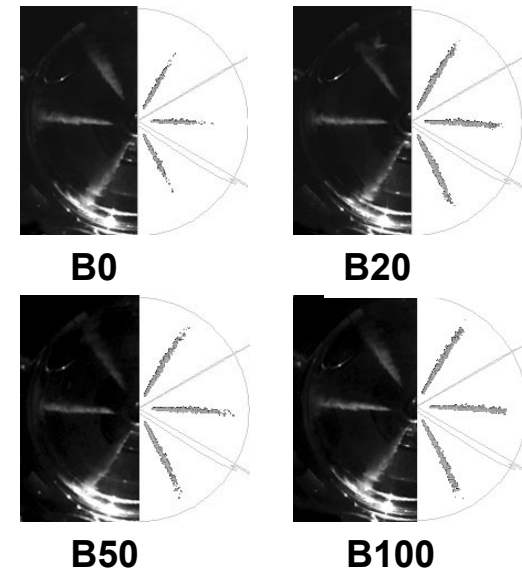
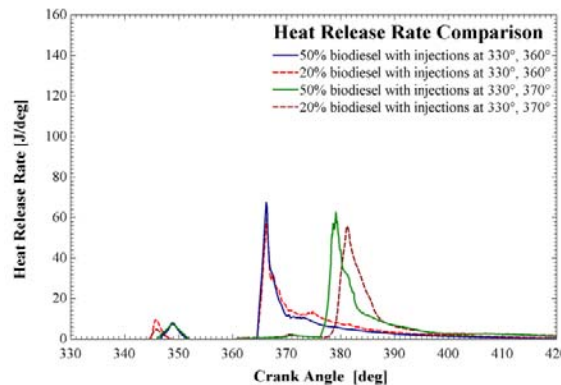
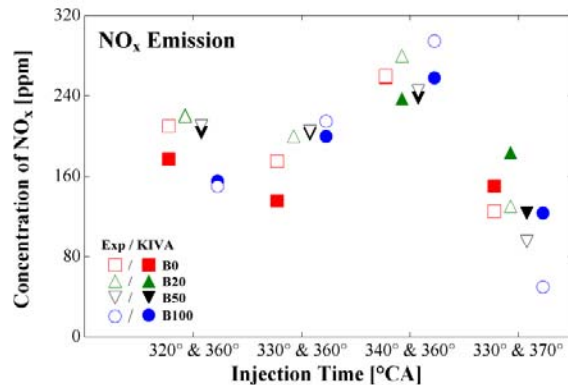
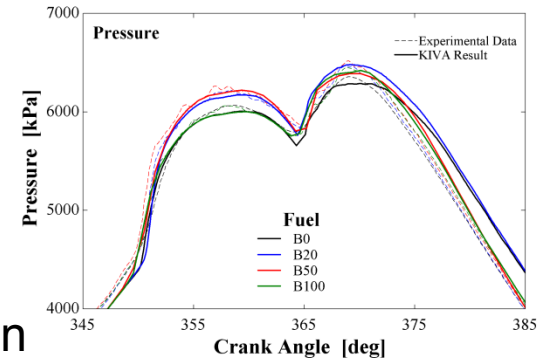


Soot emission
1500 rpm



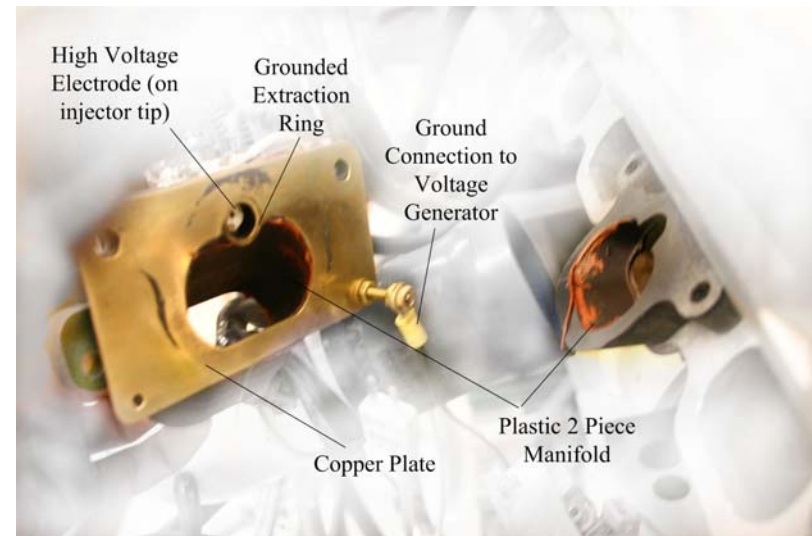
Low Temperature Combustion with Biodiesel

- Modelling improvements are included in KIVA for better compatibility with biodiesel simulations
 - A crevice flow model to model flows in the crevice volume
 - Expanded fuel library was to include properties for biodiesel
 - Multi-component model for fuel blends was included
- KIVA predicts the engine operations with biodiesel well
- Blends with more biodiesel shows stronger spray penetration
- Longer ignition delay for the initial injection for biodiesel
- Faster combustion rate for biodiesel
- Biodiesel may not cause increase in NO_x

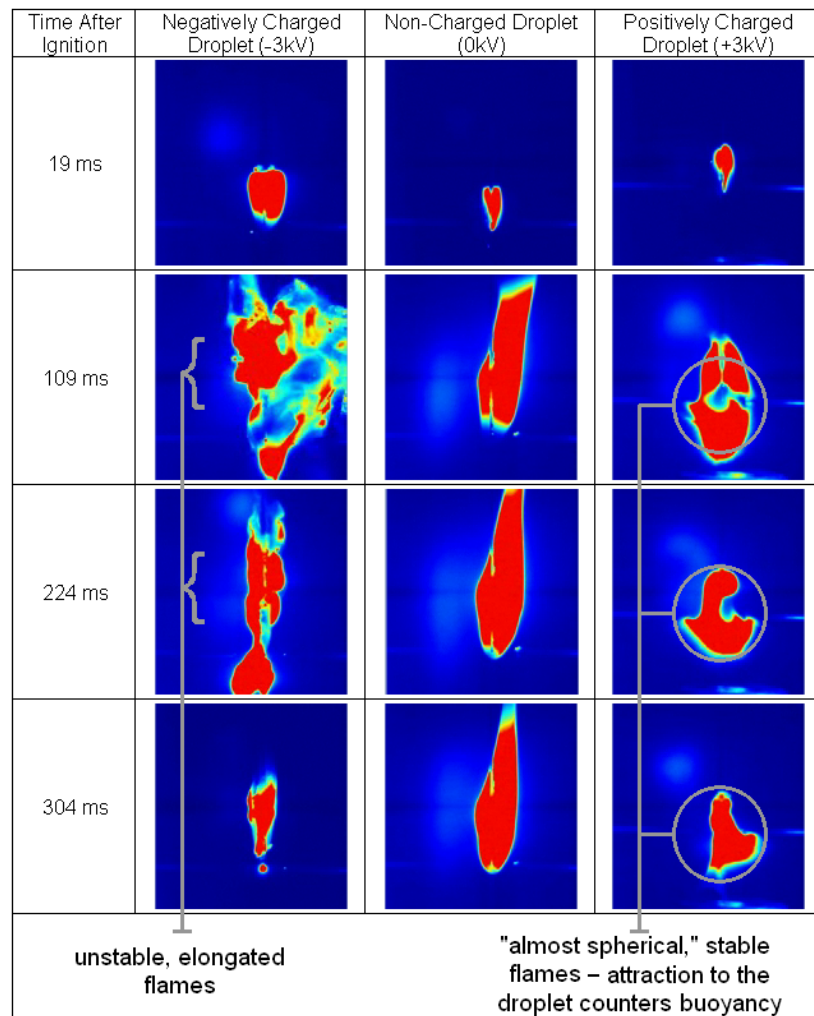


Accomplishments – Research: Adaptation of electrostatically assisted atomization of to a practical engine

- A 2000 Ford Mustang Cobra V8 that will be used for instructional purposes in the ME 403 (Internal Combustion Engines) course offered to all GATE-affiliated students was modified so that it could also be used for the study of electrostatically assisted port injection.
- Intake system was successfully modified in order to introduce electrostatic assistance to the port fuel injection.
- Successful runs with with 100% ethanol, which has an electrical conductivity four orders of magnitude higher than that of hydrocarbon-based fuels.
- Peak cylinder pressure increased by 5% for application of 1 kV voltage with constant injector pulsewidth and intake manifold pressure.
- So far, we have established a 5% decrease in NO_x per unit of power output. Unburned hydrocarbon and CO emissions not measurably affected by electrostatic assistance. A more detailed study that will take this beyond the feasibility level will be pursued in future work.

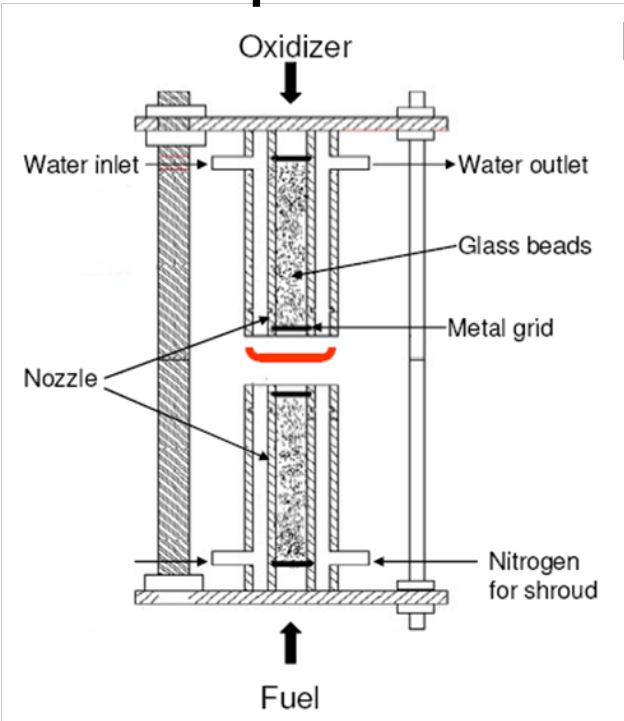


Accomplishments: Combustion of electrostatically charged bio-fuels



- Electrostatically charging the fuel, which is possible for alcohol-containing biofuels that have a much larger electric conductivity than hydrocarbon-based fuels, can be used in order to drastically alter the morphology of droplet combustion.
- Charging the fuel with negative electrostatic charge causes intense unstable motions of the flame around single-burning droplets in normal gravity, which can reduce the droplet burning time by as much as 40% in isooctane - ethanol blends.
- Positive charging of the droplet generated almost spherical flames indicating an electrostatic attraction of negative particles in the flame that countered the effect of buoyancy.
- The effect of electrostatics is coupled with combustion chemistry: Ethanol-containing and anti-static-additive-containing isooctane mixtures of the same conductivity burn differently.

Accomplishments: Experimental and Theoretical tools for fundamental bio-fuel combustion studies



a. Counter-flow burner

- A counterflow burner was established and equipped with laser diagnostics (Raman, fluorescence) for fundamental studies of strained, non-premixed bio-fuel flames.
- Butanol and butanol-containing mixtures are the first fuels that are tested because of recent advances in butanol production from biological sources and its significantly higher energy content compared to ethanol.
- An apparatus that fully pre-vaporizes butanol and studies gaseous strained flames has been established.

b. Theoretical investigation of combustion in compositionally stratified media

- It was established theoretically that flame propagation in mixtures of varying composition cannot be analyzed as a series of flamelets propagating at the flame speed corresponding to the local equivalence ratio but is rather determined by parameters that relate to history of propagation.
- Rich and lean stratified combustion are drastically different in terms of flame propagation and stability



Future Work

Activities for Next Fiscal year

- Strengthen collaborative efforts with industry partners and the Energy Biosciences Institute
- Pursue student and faculty exchange with international collaborators
 - Leverage PI contacts and existing collaborations with institutions and industries in Europe, Asia, Africa and Brazil
- Participate actively in college and campus initiatives related to bioenergy and sustainability
 - Membership on organizing committees of initiatives in the Colleges of Engineering and ACES
 - Integration of GATE curricula and certification in graduate programs
- Conduct research in emerging biofuel technologies
 - Investigate properties and engine processes of next generation biofuels
 - Investigate the possibility of “upstream” savings in biofuel production through appropriate tuning of “downstream” technologies
 - Emphasize energy efficiency in engine research

“Maximizing energy efficiency and decreasing energy use will remain the lowest hanging fruit for the next several decades. It is something that we should do and we must do.” Steven Chu-U.S. Energy Secretary





Summary

- In its second year of operation, the GATE Center on Advanced Automotive Bio-Fuel Combustion Engines at UIUC supported the research of 7 Ph.D. candidates and involved 26 students in an interdisciplinary curriculum that offered instruction on agricultural, biological, chemical, mechanical and economical aspects of emerging bio-fuel technologies.
- A syllabus leading to GATE certificate was established, one class was completely revised (Combustion Fundamentals) and one new class was introduced (Experimental Methods of Fluid Mechanics).
- The research activity of GATE Fellows and involved faculty produced 21 archival publications, one book chapter and 18 conference presentations on biofuel research.
- Industrial and international partnerships were initiated or strengthened through faculty presentations and student internships. Direct involvement in the BP Energy Biosciences Institute at UIUC continues to provide an avenue for fruitful collaborations.
- Center participation in an Energy and Sustainability Engineering (EaSE) Graduate Option program provides broader opportunities for students and faculty